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Field Evaluation of a Two-Stage ESP for High Resistivity Dusts

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16. ABSTRACT

The paper gives results of tests of new, two-stage pilot scale ESP system, consisting of a precharger and a downstream collector, on a high-resistivity fly-ash at a coal-fired power plant. Operating on a 0.47 m^3/s slipstream, the system had a specific collecting area of 50.4 $m^2m^{-3}s^{-1}$. With an inlet mass loading of 18 g/m^3, and a dust resistivity of 1.97×10^{11} cm, an overall average collection efficiency of 97.7% was achieved. When the precharger was turned off, a collection efficiency of 83.4% was recorded. Although the plate area of the precharger is only about 3% of that of the entire system, the effect of energizing the precharger is approximately equivalent to doubling the collecting area of the system.

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Elektrofilter kleinere Partikel generell schlechter als größere abgeschieden werden. Signifikante Einflüsse der Filterparameter Gassenbreite, Gasgeschwindigkeit und Sprühelektrodenzahl waren nicht feststellbar.

Zur Bestimmung der Staubkonzentrationsverteilung in der Gasse des Elektrofilters verwendete man eine optische Methode. Unter bestimmten Annahmen, z. B. daß die Partikelgrößenverteilung des Staubes sich zu den Niederschlagselektroden hin nicht wesentlich ändert, wurden die gemessenen Profile als Staubkonzentrationsprofile interpretiert. Bei allen Profilen war ein deutliches und in etwa lineares Anwachsen von der Gassenmitte zu den Niederschlagselektroden hin zu erkennen. Alternativ kann man auch von einer Konzentrationsverringerung zur Mitte der Gasse hin sprechen. Gesetzmäßige Einflüsse der Gassenbreite und der Gasgeschwindigkeit auf die Konzentrationsänderungen waren nicht sicher nachweisbar.

Als für die Praxis wohl wesentlichstes Ergebnis der Untersuchungen ist die Proportionalität von Gassenbreite und Wanderungsgeschwindigkeit hervorzuheben. Dies besagt, daß bei vergrößerter Gassenbreite und demzufolge auch vergrößertem Volumenstrom der Abscheidegrad erhalten bleibt. Groß-Elektrofilter enthalten in der Regel zahlreiche parallele Gassen. Eine Einsparung von Einbauten durch Vergrößern der Gassenbreite ist deshalb naheliegend. Bei gleichbleibender Filtereffektivität würde der Materialaufwand entsprechend reduziert werden. Ein weiterer Vorteil ergibt sich aus der Überlegung, daß die stets vorhandenen Dejustierungen der Elektroden relativ gesehen geringer gehalten werden könnten. Zusätzlich können größere Gassenbreiten auch für die Abscheidung von Stäuben mit hohem Widerstand günstiger sein [8].

Aufgrund der gewonnenen Ergebnisse ist es sinnvoll, die an der Laboranlage durchgeführten Untersuchungen an einer Pilotanlage zu überprüfen, die direkt hinter einem industriellen Stauberzeuger installiert ist. Ein entsprechender Staubabscheider für eine Durchsatzmenge von max. 36000 m^3 Gas/h ist derzeitig im Bau.

Sollten sich die Ergebnisse der Laboranlage als übertragbar erweisen, ist es wirtschaftlich interessant, Elektrofilter mit größeren Gassenbreiten als bisher zu bauen.

[ST 275]

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Field evaluation of a two-stage ESP for high resistivity dusts

By D. H. Pontius, P. V. Buch and L. E. Sparks

A new, two-stage pilot scale ESP system, consisting of a precharger and a downstream collector, has been tested on a high resistivity flyash at a coal-fired power plant. Operating on a 0.47 m^3/s (1000 ACFM) slipstream, the system had a specific collecting area of 50.4 $m^2\ m^{-3}\ s^{-1}$ (256 ft^2/1000 ACFM). With an inlet mass loading of 18 g/m^3 (8.1 gr/SCF), and a dust resistivity of $1.97 \times 10^{11}\ \Omega$ cm, an overall average collection efficiency of 97.7% was achieved. When the precharger was turned off a collection efficiency of 83.4% was recorded. Although the plate area of the precharger is only about 3% of that of the entire system, the effect of energizing the precharger is approximately equivalent to doubling the collecting area of the system.

Ein neues zweistufiges elektrostatisches Präzipitatorsystem im Versuchsmaßstab, das aus einem Vorauflader und einer Sammelelektrode abgasseitig besteht, wurde in einem kohlegefeuerten Kraftwerk mit Flugasche hohen Widerstandes geprüft. Bei einem Durchsatz von 0,47 m^3/s (1000 ACFM) hatte das System eine spezifische Sammelfläche von 50,4 $m^2\ m^{-3}\ s^{-1}$ (256 ft^2/1000 ACFM). Bei einer Massenbeladung von 18 g/m^{-3} (8,1 gr/SCF) und einem Staubwiderstand von $1{,}97 \cdot 10^{11}\ \Omega$ cm wurde ein Gesamtentstaubungsgrad von 97,7% festgestellt. Wurde das Vorauflagegerät ausgeschaltet, wurde ein Entstaubungsgrad von nur 83,4% gemessen. Obwohl die Plattenfläche des Vorauflagegerätes nur 3% des Gesamtsystems betrug, lag der Effekt bei Anwendung des Vorauflagers in der Größenordnung, die die Verdopplung der Sammelfläche des gesamten Systems gebracht hätte.

On a examiné un nouveau système de précipitateur électrostatique à deux étages à l'échelle expérimentale, ce précipitateur consiste en un préchargeur et en une électrode collective du côté de l'échappement des gaz, cette expérience a été faite dans une centrale électrique à charbon avec des poussières volantes à haute résistance. Pour un flux de 0,47 m^3/s le système avait une surface spécifique collective de 50,4 $m^2\ m^{-2}\ s^{-1}$ (256 ft^2/1000 ACFM). Pour une charge de masse de 18 g/m^{-3} (8,1 gr/SCF) et pour une résistance de poussière de $1{,}97 \cdot 10^{11}\ \Omega$ cm on a constaté un degré total de dépoussiérage de 97,7%. En excluant l'appareil préchargeur on mesure un degré de dépoussiérage de 83,4%. Bien que la surface de la plaque de l'appareil préchargeur ne comporte que 3% du système total, l'effet de l'application du préchargeur se situe dans l'ordre de grandeur qu'aurait produit le redoublement de la surface collective du système entier.

Schlagwörter: Abscheider / Elektrostatik / Abscheidung-, Schwebstoff / Entstaubung

Field evaluation of a two-stage ESP for high resistivity dusts

1 Introduction

The phenomenon variously termed back corona or reverse ionization has been recognized for many years as a serious impediment to the process of electrostatic precipitation of particulate materials that have high electrical resistivity [1]. (In general, a value in excess of approximately 5×10^{10} Ω cm, as measured by currently available techniques at electric fields near breakdown, will lead to problems involving back corona.) Dusts having high resistivity are not intrinsically difficult to precipitate i.e. resistivity does not affect charging, but the presence of a layer of such material on the collecting surfaces of a conventional electrostatic precipitator (ESP) modifies the electrical behavior of the system. In the deposited dust layer the electric field strength, calculated as the product of the resistivity and the current density, may become great enough to cause electrical breakdown. Since the breakdown generally results in localized regions of high current density, the ion current outside the dust layer tends to converge on the breakdown sites, and an enhancement of the local electric field strength occurs. The field may, in fact, become great enough to produce ionization at or near the breakdown sites. The result is an injection of ions from the collection electrode, hence a "back corona". The polarity of these ions will be opposite that of the ions originating at the corona discharge electrode. Consequently, the particle charging process, essential to the collection of particles in the electric field, will become degraded as the ion distribution becomes bipolar.

The resistivity of flyashes resulting from the combustion of coal depends upon a number of factors, including temperature and chemical composition [2]. An important correlation, for example, can be shown in the relationship of resistivity to sulfur content. A coal having a low level of sulfur has the advantage of producing relatively small concentrations of sulfur oxides when burned, but the resulting ash can be expected to have a high resistivity. Hence a high resistivity ash has been found to be a problem at many coal-fired power plants that use low-sulfur coal.

Several methods have been used successfully in dealing with the problem of precipitating high resistivity flyashes, but the costs of installation or operation are generally quite high in comparison with those of ESP systems where ash resistivity is not a problem. Examples include "hot side" ESP's, devices with very large collecting surfaces, and provisions for adding various chemical "conditioning" reagents to the coal or flue gas.

This paper describes the development and testing of a novel two-stage ESP designed specifically to overcome the effects of back corona. The work was performed at *Southern Research Institute*, Birmingham, Alabama, and was sponsored by the *U.S. Environmental Protection Agency, Particulate Technology Branch, Industrial Environmental Research Laboratory*, Research Triangle Park. The concept and theory of operation will be described, followed by a summary of the developmental program, and a presentation of the results of a pilot-scale field evaluation indicating technical feasibility and cost effectiveness.

2 Theory of operation

Since back corona interferes with electrostatic precipitation principally by degrading the particle charging effectiveness of a system, the approach applied to the problem was to separate the charging and collection functions as much as possible and to deal directly with back corona in the region where the particle charging process was emphasized. Thus, a two-stage concept was developed. In the first stage, or "precharger", a novel electrode arrangement and energization technique provided for relatively high current density while suppressing the effects of back corona [3; 4] (Patent pending, *D. H. Pontius* and *W. B. Smith*). The second stage was a downstream collector, designed to operate at a high electric field strength and relatively low current density. Since particle charging is accomplished in the first stage, an ion current in the second stage is required only to minimize reentrainment.

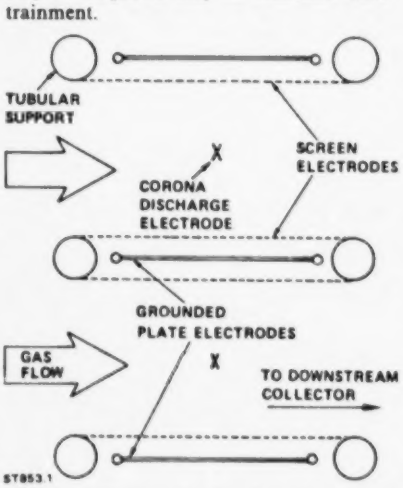

Figure 1: Cross-sectional schematic diagram showing relative positions of electrodes in the precharger

Particle charging is essentially completed within the first few centimeters of passage through an ESP [1]. Consequently, the precharger stage needs to extend only a short distance along the direction of gas flow. The relatively small size of a precharger permits the application of unusual methods and materials for control of back corona without a prohibitive cost impact on the control device.

The method for controlling back corona in the precharger is based on inserting a screen electrode near the collecting surface, and biasing the screen in such a way as to remove the ions resulting from back corona before they can drift into the active charging space. The general concept is illustrated in **Figure 1** as applied to a parallel wire-plate geometry. In operation the corona discharge electrode is energized at a high voltage, as in a conventional ESP: in addition, a voltage of the same polarity but much lower magnitude is applied to the screen electrode. For example, negative corona discharge ions approaching the screen electrode are deflected toward the openings, and thus proceed to the plate. The screen voltage is set so as to result in a screen current of zero. Now, when highly resistive particles are introduced into the system, some are unavoidably captured on the plate electrode, and back corona may occur. But the resulting positive ions are attracted to the screen electrode, and thereby prevented from entering the region between the screen and corona wire where the principal charging activity takes place. (Back corona from the screen does not occur since the screen accepts no negative ions from the primary corona discharge.)

Operational feasibility of the system was established as a result of a number of tests in the laboratory [3; 5]. It was therefore decided to construct a small pilot scale system for evaluation in the field under realistic flue gas and particulate loading conditions.

3 Preparation and testing in the field

The primary consideration in the selection of a test site was the presence of a flyash having resistivity above 5×10^{10} Ω cm. A 900 MW steam plant was located, where the use of a low-sulfur coal produced a flyash having electrical resistivity of 1 up to 2×10^{11} Ω cm at a temperature of approximately 135 °C. A convenient location was made available for setting up a pilot ESP system.

The pilot scale device was designed for a nominal flow rate of approximately 0.47 m^3/s (1000 ACFM), at a specific collecting area of 50.4 $m^2 m^{-3} s^{-1}$ (256 $ft^2/1000$

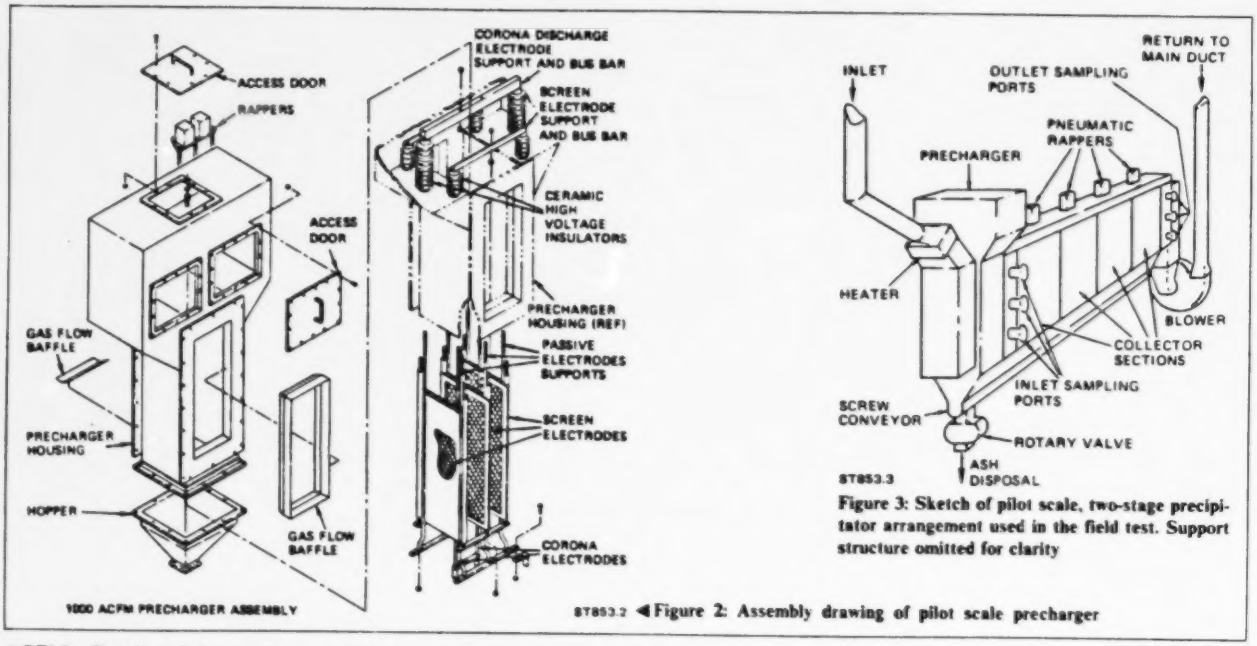

Figure 3: Sketch of pilot scale, two-stage precipitator arrangement used in the field test. Support structure omitted for clarity

Figure 2: Assembly drawing of pilot scale precharger

ACFM). Details of the precharger design are shown in **Figure 2.** There are two parallel lanes through the system: each is 1.2 m (4 ft) high and 19.0 cm (7.5 in.) wide. The screen electrodes are parallel to the plates, at a distance of approximately 1.9 cm (0.75 in.).

The downstream collector is similar in nature to a conventional parallel wire-plate ESP, except that an open mesh wire screen is used as a corona discharge electrode. That type of electrode was selected on the basis of a laboratory investigation of various corona configurations for the production of low current densities at high values of average electric field strength [3]. The collector is made up for four sections, each having 6.0 m^2 (64 ft^2) of plate area in two parallel lanes.

The overall configuration of the pilot system as installed at the test site is presented in **Figure 3.** The flue gas was extracted from the ducting at a point approximately 18 m (60 ft) above the pilot unit. An electric heater was included ahead of the pilot system in order to replace heat lost from the flue gas in the long run of connecting ductwork.

The general objectives of the test program were to establish the characteristics of the flue gas and particulate material, to determine the charging effectiveness of the precharger, and to measure the particle collection efficiency of the system both with the precharger on and precharger off. Established measurement techniques and equipment were used, including mass trains, impactors, and electrical and optical sizing devices. The chemical composition of the flue gas was measured and the ash resistivity was determined. In order that a comparison could be made with a conventional electrostatic precipitator of similar scale, a mobile system, developed by the *Environmental Protection Agency, Industrial Environmental Research Laboratory,* Research Triangle Park, N.C., and operated by *Acurex Corporation,* was brought to the test site and was connected to the same slipstream used for the new, two-stage system. The two systems were operated at similar conditions of gas velocity and specific collection area.

4 Test results

No significant difficulties were encountered in setting the pilot system into full operation. An immediate and substantial space charge effect was noted, however, resulting in values of current density much lower than anticipated on the basis of previous laboratory studies. It was determined that the cause of the space charge was a very heavy inlet dust burden, averaging approximately 18 g/m^3 (8.1 gr/SCF). In spite of this unexpectedly large loading, preliminary tests of particle charging effectiveness showed that the system was performing well, and hence no modifications to the test plan were necessary.

The test period covered 14 days, during which time the flue gas conditions and flyash resistivity remained reasonably stable. The average temperature at the inlet of the pilot device was 120 °C (248 °F), which was within 7 °C of the main duct temperature. Results of the gas analysis are presented in **Table 1.** An in situ probe was used for making measurements of ash resistivity, both in the main duct near the point of extraction (49 measurements) and at the inlet

Table 1: Flue gas conditions and flyash resistivity

Date	Volume %			ppm v/v		Resistivity Ωcm
	CO_2	O_2	H_2O	SO_2	SO_3	
9-08-79	10.4	8.9	6.6	508	0.8	1.70×10^{11} (a)
9-11-79	12.1	6.6	6.8	562	0.3	1.06×10^{11} (a)
9-12-79	12.4	7.2	7.0	539	0.4	2.15×10^{11} (a)
9-13-79	12.0	6.6	7.2	581	0.9	1.69×10^{11} (a)
9-14-79	11.8	7.8	6.6	568	1.0	1.91×10^{11} (a)
9-15-79	12.4	7.0	6.5	552	1.1	0.95×10^{11} (b)
9-17-79	12.2	7.4	6.4	521	0.6	1.02×10^{11} (b)
9-18-79	12.8	7.1	7.2	531	0.6	1.01×10^{11} (b)
9-19-79	12.8	6.8	6.8	556	0.7	4.02×10^{11} (b)
9-20-79	11.2	8.3	6.0	510	0.8	2.84×10^{11} (b)
Averages	12.0	7.4	6.7	543	0.7	1.84×10^{11}

(a) – measured in flue gas mainstream
(b) – measured in pilot-scale ESP test port

of the pilot device (17 measurements). The average values measured at these two locations were 1.70×10^{11} Ωcm and 1.97×10^{11} Ωcm, respectively.

The charging effectiveness of the precharger was determined by two methods: one provided the overall ratio of charge to mass (Q/m) for the polydisperse distribution of particles, and the other gave charge measurements for individual particles. For both methods, comparisons with established particle charging theories were made.

Individual particle charges were measured by means of an apparatus similar to that used for the classical *Millikan* oil drop experiment, in which a particle is suspended against the force of gravity by an electrostatic field acting on the particle's charge. A total of 582 single-particle measurements were made, where diameters ranged from 0.3 μm to 1.5 μm. The results of these measurements are presented in **Figure 4**, along with theoretical-calculations based on the charging conditions in the precharger [6].

Overall ratio of charge to mass was determined by capturing samples on a filter held in an electrically isolated enclosure. The total accumulated charge was measured with an electrometer, and the sample was weighed. The average value of Q/m obtained was -2.08 μC/g, which is consistent with the results of individual charge measurements summed over the particle size distribution, and with previous empirical results obtained in the laboratory.

The agreement between the values of charge on the particles as determined theoretically and experimentally indicates that back corona effects were in fact under control, since such effects were ignored in the calculations. The ion density was derived directly from the primary corona current. The screen current was not taken into consideration because, according to the principle of operation of the *Pontius-Smith* Precharger, none of the screen current penetrates into the active charging region. In the presence of back corona the measured values of particle charge would be significantly smaller than the computed values. Thus, the precharger permitted particle charging of high resistivity flyash to levels comparable with those achieved in conventional ESP systems on ashes having low-to-moderate values of electrical resistivity.

The downstream collector, comprising four identical sections, was operated at the maximum voltage attainable without excessive sparking. The electrical behavior was nearly uniform among the sections. Typical voltage-current curves are given in **Figure 5**. Because of the heavy dust loading the average current density was quite low – less than 1 nA/cm². The average electric field strength was approximately 3.2 kV/cm. The relatively low values of current density were probably a result of space-charge loading due to the high level of dust burden previously mentioned. This conclusion is confirmed by the fact that very similar values of current density were measured in the conventional mobile system operated on the same slipstream.

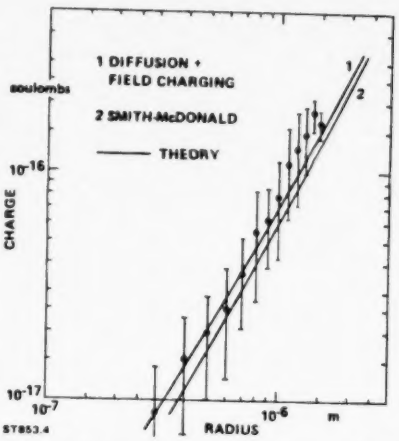

Figure 4: Comparison of measured values of particle charge with theoretical calculation based on precharger operating parameters

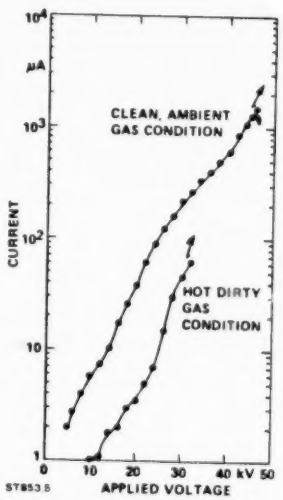

Figure 5: Electrical characteristics of the first field in the collector stage. The very low current levels in the hot, dirty gas condition result from space charge loading

During the test period, measurements of inlet and outlet mass loadings were made in order to evaluate the collection efficiency of the downstream collector alone (precharger off) and the complete two-stage system (precharger on). Measurements were also made using an electrical aerosol analyzer (*Thermosystems* Model 3030) and an optical particle counter (*Climet Model* 208 B).

Overall system performance and the effect of the precharger can be observed from the results of EPA Method 17 mass train measurements, summarized in **Table 2.** The downstream collector alone operated with an overall collection efficiency of 83.41%. That value is quite low; however, the relatively small specific collection area could not be expected to produce a high level of performance operating on a high resistivity dust. With the precharger turned on, the collection efficiency of the two-stage system averaged 97.71%. Thus the penetration of the system (100%-Efficiency) was lower by a factor of 7.2 with the precharger on than when it was turned off.

Measurements made on the EPA/IERL-RTP mobile system indicated an average overall collection efficiency of 91.9%. The penetration of the conventional system was approximately 3.5 times as great as that of the new, two-stage system, although the penetration of the collector stage alone in the new system (precharger turned off) was 2.1 times that of the conventional ESP).

Values of fractional efficiency for particles in the range of approximately 0.01 μm

Table 2: Results of mass train measurements

Date	Inlet Loading, g/m³	Outlet Loading, g/m³		Collection Efficiency, %	
		Precharger on	Precharger off	Precharger on	Precharger off
9-08-79	17.53	0.469		97.32	
9-11-79	18.86	0.487	3.04	97.42	83.88
9-12-79	18.95	0.563		97.03	
9-13-79	21.39	0.455	3.94	97.87	81.58
9-14-79	13.68	0.384		97.19	
9-15-79	19.02	0.339	2.75	98.22	85.54
9-17-79	19.61	0.570		97.09	
9-18-79	17.85	0.208	3.09	98.83	82.69
9-19-79	17.87	0.336		98.12	
9-20-79	19.75		2.47		87.49
Averages	18.45	0.423	3.06	97.71	83.41

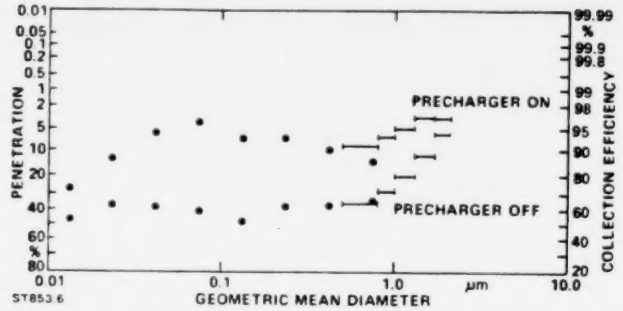

Figure 6: Collection efficiency of the two-stage system with precharger on and precharger off, as determined by use of an Electrical Aerosol Analyzer (filled circles) and an Optical Particle Counter (horizontal bars)

to 3.0 μm diameter were determined using an electrical aerosol analyzer (EAA) and an optical particle counter (OPC). The results, as displayed in **Figure 6**, support those derived from the mass train measurements. The large enhancement in performance due to the action of the precharger is clearly effective throughout the range of particle sizes covered by these instruments.

Cascade impactors were used to measure particle size distributions at the inlet and at the outlet of the system. The effect of the precharger can be seen most clearly by comparing the outlet measurements made when the precharger was energized with those taken when it was turned off. Results of these measurements are given in **Figure 7**, averaged over 24 impactor runs with the precharger on and 10 runs with the precharger off. The penetration of the system (directly proportional to the outlet mass loading) is consistently much lower with the precharger on than when the collector is operated alone. The average reduction in penetration due to the use of the precharger is by a factor of 10.5. Although this value is somewhat higher than that derived from the mass train readings, the trend is consistent.

It is significant that all tests completed thus far, at various scales and with both redispersed flyash and actual flue gas, have produced consistent results. Laboratory experiments were performed in which prechargers of two different designs, both embodying the three-electrode configuration described in this paper, were tested [3]. The results, in general, showed a reduction by approximately a factor of 7 in the dust penetration of the two-stage system, as compared with that of the down-stream collector alone. The agreement between the laboratory studies and the field tests indicate that the fundamental physical principles are sound, and that scale-up problems should be minimal.

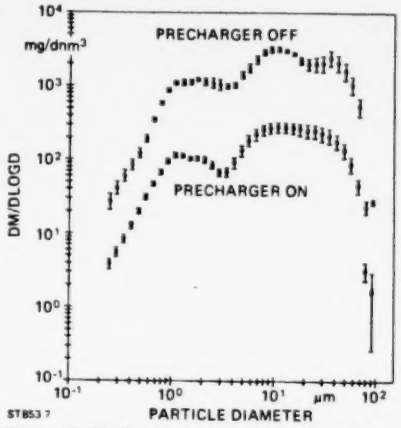

Figure 7: Outlet particulate mass loading as a function of particle diameter with precharger on and precharger off. Measurements were made with inertial cascade impactors

5 Conclusions

The field test of the pilot scale two-stage ESP system confirms the laboratory results achieved previously. Reductions in penetration due to the action of the precharger are roughly equivalent to doubling the specific collection area of the down-stream collector, while the plate area of the precharger adds only about 3% to that of the entire system.

The cost of fabricating a precharger of the type used in this work is estimated at 10 up to 15% of the cost of a complete two-stage system, based on engineering estimates for a semiworks system now being fabricated. Thus potential savings of the order of 40% over the conventional technology may be projected for this new system in applications to the collection of high resistivity dusts.

6 Acknowledgements

We are grateful to *S. P. Schliesser* of *Acurex Corporation* for his efforts in providing the use of the *EPA/IERL*-RTP mobile ESP and operating personnel in order that a comparison between this conventional device and the new, two-stage system could be made. The work of *J. D. McCain* and *G. H. Marchant*, both of *Southern Research Institute*, in arranging for test crews and equipment used in making the necessary measurements, is also gratefully acknowledged.

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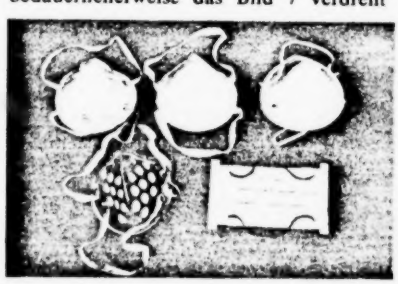
Berichtigung

Im Aufsatz *Riediger, Wolf, Fahrbach:* Prüfung von filternden Atemschutzgeräten, diese Zeitschrift 40 (1980) Nr. 9, S. 391 ist bedauerlicherweise das Bild 7 verdreht abgedruckt worden, wodurch die Zuordnung der Gesamtleckagen (im Text) zu den entsprechenden Maskentypen nicht richtig ist. Richtig ist folgende Text-Bild-Kombination:



Mit diesem Verfahren wurden für die in **Bild 7** gezeigten Maskentypen in orientierenden ersten Versuchen folgende Werte für die Gesamtleckage gefunden:

obere Reihe in Bild 7, von links nach rechts

1. Maske 9% bis 18%
2. Maske 9% bis 13%
3. Maske 36% bis 47%

untere Reihe in Bild 7, von links nach rechts

1. Maske 25% bis 43%
2. Maske 20% bis 24%